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CR-171728

USER MANUAL OF THE CATSS SYSTEM
(VERSION 1.0)
COMMUNICATION ANALYSIS TOOL FOR SPACE STATION



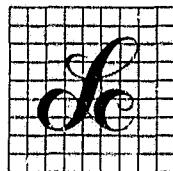
PREPARED FOR
NASA LYNDON B. JOHNSON SPACE CENTER
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CONTRACT NO. NAS 9-16868

(NASA-CR-171728) USER MANUAL OF THE CATSS
SYSTEM (VERSION 1.0) COMMUNICATION ANALYSIS
TOOL FOR SPACE STATION Interim Report
(LinCom Corp., Los Angeles, Calif.) 45 p
HC A03/MF A01

N84-17431

Unclassified
CSCL 17B G3/32 11638

NOVEMBER 1983



TR-1183-8314

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1. Introduction

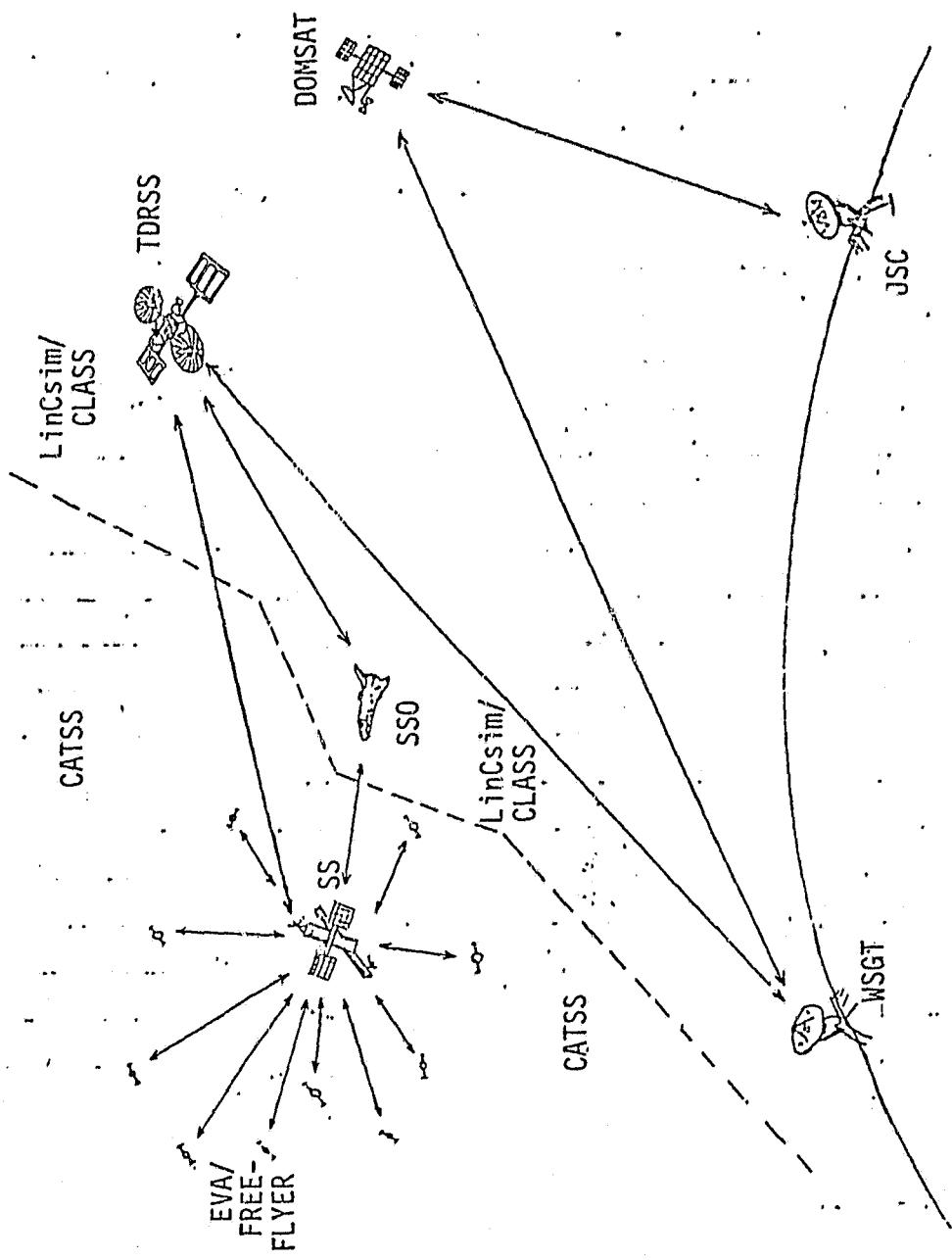
The Communication Analysis Tool for the Space Station (CATSS) developed for NASA/Johnson Space Center is a FORTRAN language software package capable of predicting the communications links performance for the Space Station (SS) communication and tracking (C & T) system as shown in Fig. 1. It is an interactive software package currently developed to run on the DEC/VAX computers. The CATSS models and evaluates the various C & T links of the SS, which includes the modulation schemes such as Binary-Phase-Shift-Keying (BPSK), BPSK with Direct Sequence Spread Spectrum (PN/BPSK), and M-ary Frequency-Shift-Keying with Frequency Hopping (FH/MFSK). Optical Space Communication link is also included. Table 1 shows the CATSS models relative to the current SS links.

CATSS is a C & T system engineering tool for SS design. It can be used to predict and analyze the system performance for different link environment. Identification of system weaknesses can be achieved through evaluation of performance with varying system parameters. System tradeoff for different values of system parameters can be made based on the performance prediction. With all these functional capabilities, CATSS serves as an essential and inevitable design and operation computer-aided tool for the SS, as what the CLASS (Communications Link Analysis and Simulation System) does currently for the TDRSS.

In the chapters to follow, the design concept of the CATSS, the link models and performance capability, instruction for accessing and running CATSS, and the CATSS output will be discussed. Sample run of CATSS is also included in the Appendix.

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Fig. 1. SPACE STATION/TDRSS COMMUNICATION NETWORK



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Table 1. CATSS MODELS RELATIVE TO
CURRENT SPACE STATION LINKS

Link	Modulation Scheme	CATSS
1. Energy Section - Relay Satellite		
1.1 Forward (TDRS to SS)	PN/QPSK	
1.2 Return (SS to TDRS)	PN/QPSK, convolutional code	
2. SS - Relay Satellite		
2.1 Forward (TDRS to SS)	BPSK	✓
2.2 Return (SS to TDRS)	BPSK/QPSK convolutional code	✓
3. SS - SSO		
3.1 Forward (SS to SSO)	BPSK, convolutional code	✓
3.2 Return (SSO to SS)	BPSK, convolutional code	✓
4. SS - OTV		
4.1 Forward (SS to OTV)	PN/BPSK, convolutional code	✓
4.2 Return (OTV to SS)	PN/QPSK, convolutional code	
5. SS - EVA/Free-Flyer Multiple Access		
5.1 Forward (SS to EVA/FF)	FH/MFSK, convolutional code	✓
5.2 Return (EVA/FF to SS)	FH/MFSK, convolutional code	✓
6. SS - EVA/Free-Flyer Wideband		
6.1 Forward (SS to EVA/FF)	BPSK, convolutional code	✓
6.2 Return (EVA/FF to SS)	BPSK, convolutional code	✓

2. Design Philosophy

When the CATSS was designed and developed, the following guidelines were followed:

- (1) CATSS will serve as both a design tool in the system design stage and performance analysis tool in the system operation stage.
- (2) It will possess a maximum flexibility for any system change and expansion.
- (3) It should be easy to use and maintain.
- (4) The output data of CATSS should be arranged in the form suitable for design and evaluation purposes.
- (5) Computation time should be kept as a minimum.

In view of the above requirements, the CATSS software is coded in a logical and structural modular form so that software maintenance and expansion do not require excessive effort. Fast algorithms, e.g. recursive iterations, are applied for computation whenever it is possible. In the present stage, CATSS makes use of analytical results only and no simulation is involved. In the future, simulation may be necessary for the cases no analytical results are known. However, since computer simulation (Monte Carlo type of simulation) requires very long computation time, it is in general not a very attractive method. A compromise technique, termed analytic simulation, is one which combines the analysis and simulation together. In this case, the advantage for both analysis and simulation will be available. This analytic simulation technique is widely used in the CLASS system developed for TDRSS.

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Graphical display is an option provided by the CATSS to yield a clear and instant overview of the system performance. Due to facility constraint, the graphic display capability is developed only for terminals (CRT or hard copy). In the next phase of CATSS development, higher resolution graphic display will be developed for graphic plotter.

Fig. 2 is a software organization of the current CATSS architecture. It is a link oriented architecture by itself. The user is able to access any one of the five links at any time through the control of the CATSS control routine.

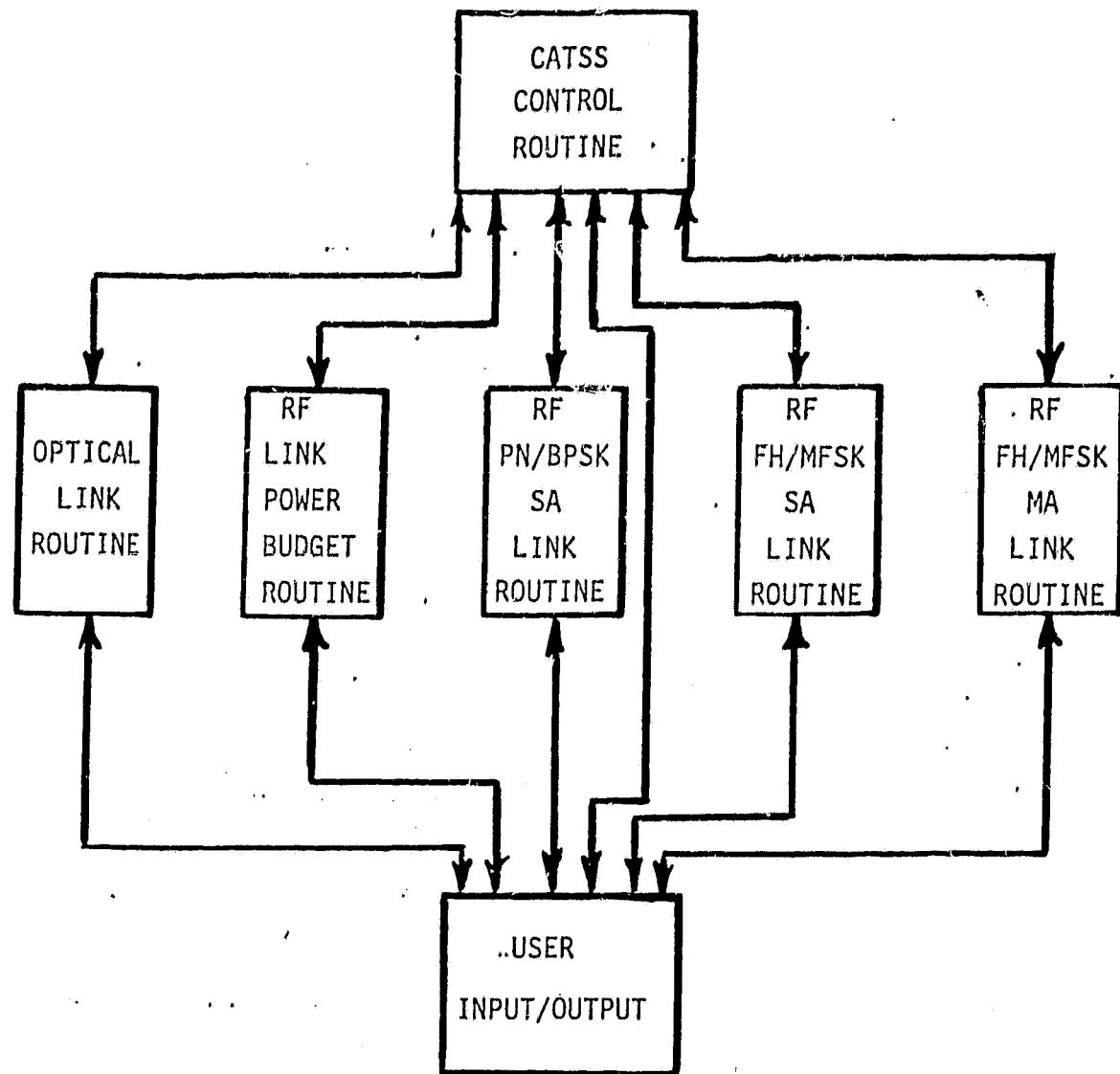
Fig. 3 shows a design procedure of the SS C/T link by using the CATSS as a design and analysis tool. An optimized system with respect to system parameters can be achieved by the recursive process as shown in the design flow chart.

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Fig. 2. CURRENT CATSS SOFTWARE

ARCHITECTURE (LINK ORIENTED)

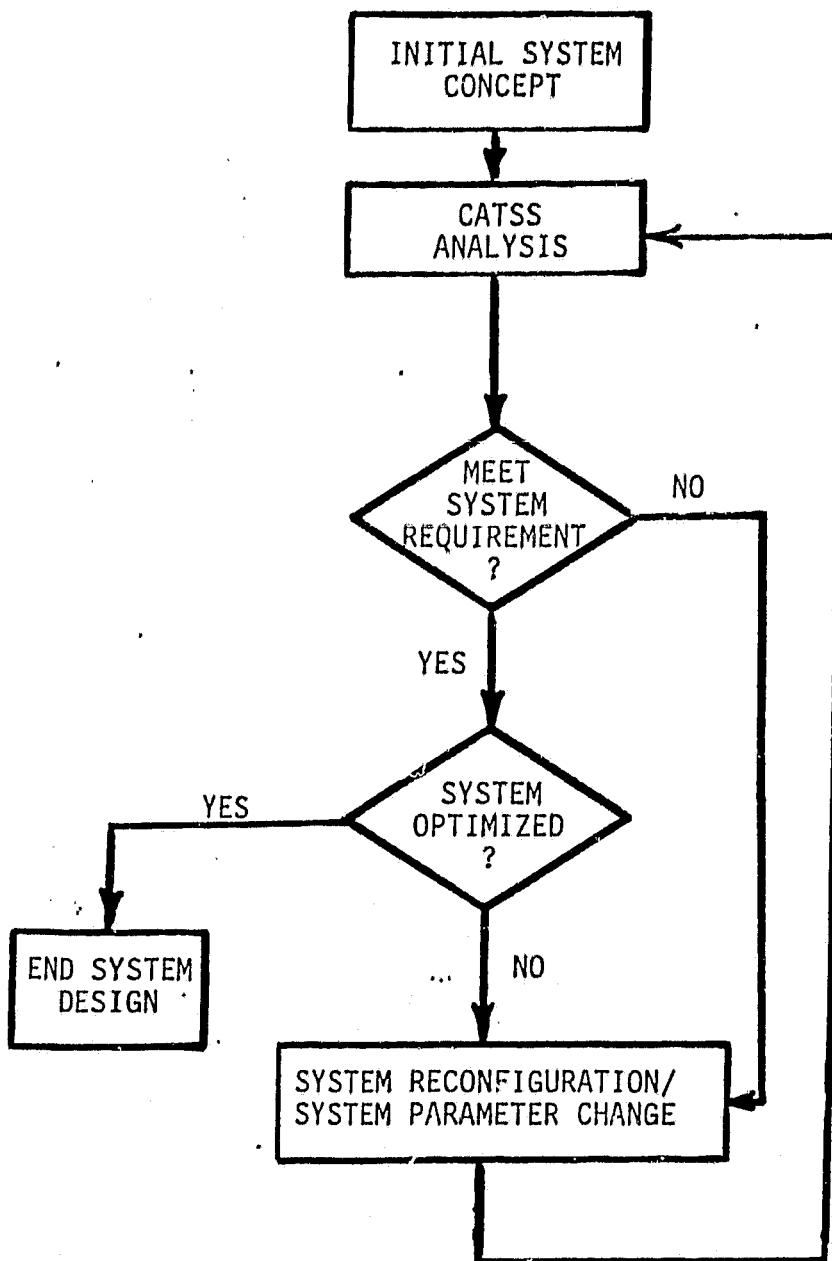
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Fig. 3. SPACE STATION SYSTEM DESIGN PROCEDURE
BY USING CATSS



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3. Link Models and Performance Capability

In this section the link models analyzed and evaluated by the CATSS are briefly discussed. Details of these models are discussed in the final report¹. The models of each link are made to be generic in nature so that they possess a high flexibility for any possible system modification and expansion. In the following sections, the models of the transmitters, channels, noise and jamming, and receivers structure are provided for each link so that interpretation of the CATSS output can be made accurately. The dimension and value range of each parameter are also indicated so that meaningless input values can be avoided.

¹ Final report on "Space Station Communication and Tracking Analysis and Simulation" LinCom Corp. Oct. 1983.

3.1 RF Link Budget

The RF link budget models the radio frequency power gain/loss over the space channel. It models the antennas gain and space loss between the transmitter and the receiver.

3.1.1 System Parameters

1. Distance (kilometer), [>0]²
2. Transmitter (parabolic) antenna diameter (meter), [>0]
3. Transmitter antenna aperture loss factor [0 to 1]
4. Receiver (parabolic) antenna diameter (meter), [>1]
5. Receiver antenna aperture loss factor [0 to 1]
6. Carrier frequency (GHz) [>0]
7. Atmospheric absorption loss (dB/Km) [> 0]

3.1.2 CATSS Output

1. Transmitter antenna gain (dB)
2. Receiver antenna gain (dB)
3. Free space loss (dB)
4. Atmospheric absorption loss (dB)
5. Total gain(loss) (dB)

3.1.3 Output Format

1. Printed Value

All values in Sect. 3.1.2

2. Graphic plot

Total gain (loss) versus input parameter

² Note that the dimension, if there is, of each parameter is given in the bracket, while its value range is provided in the square bracket.

3.2 RF Single Access with PN/BPSK

The RF single access link with PN/BPSK modulation is modeled in Fig. 4. The jamming in this link is assumed to be pulse jamming and its model is illustrated in Fig. 5.

This link can model the following SS links

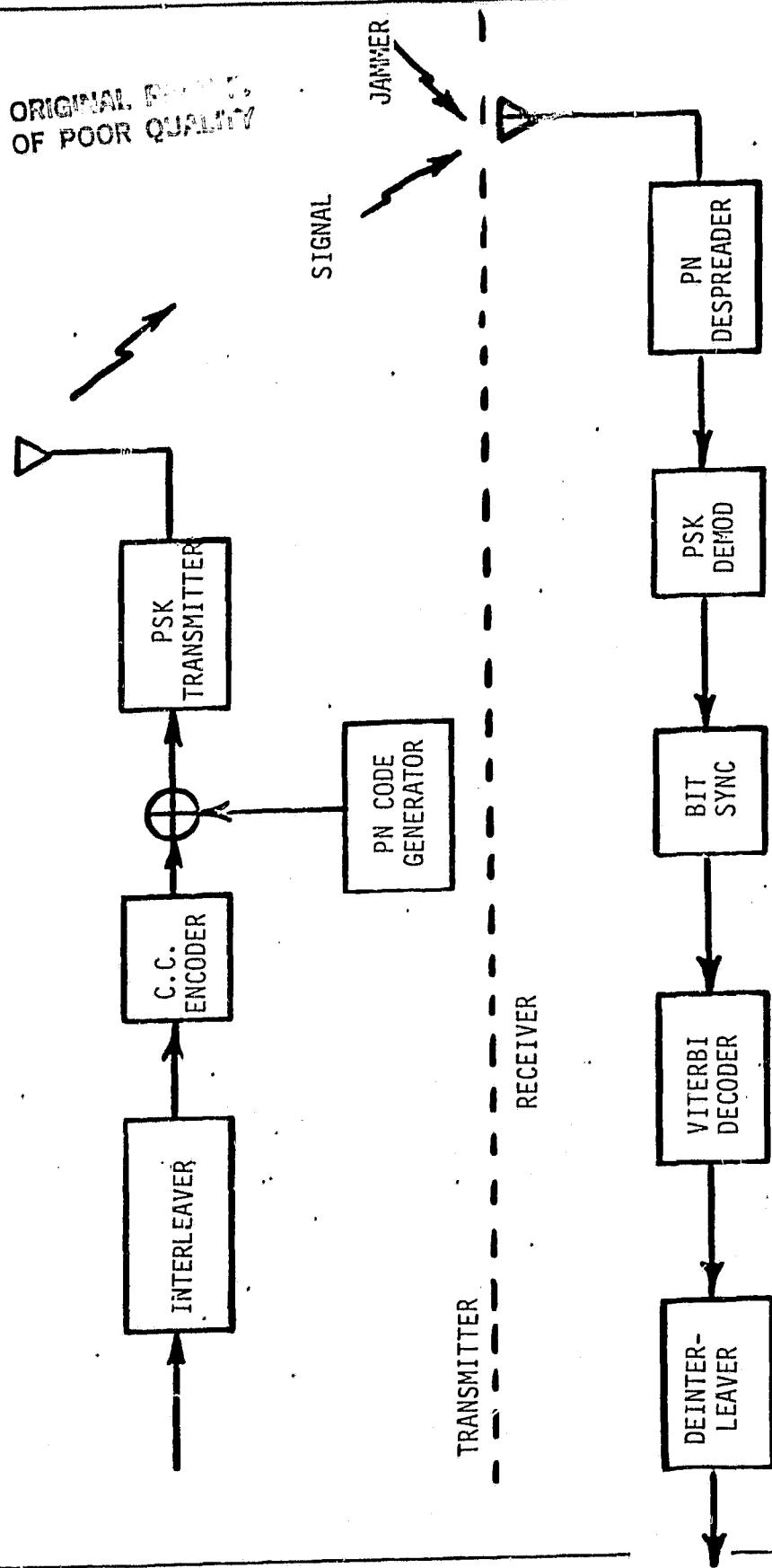
1. SS/Relay Satellite
2. SS/Space Shuttle Orbiter
3. SS/Orbital Transfer Vehicles
4. SS/EVA, Free-Flyers

3.2.1 System Parameters

1. With or without interleaving
2. With or without coding
3. Convolutional Code
 - (3.1) Best (5,1/2) convolutional code
 - (3.2) Best (7,1/2) convolutional code
 - (3.3) Best (7,1/3) convolutional code
4. Decoding Method
 - (4.1) Soft decision with interleaving
 - (4.2) Hard decision with interleaving
5. With or without correlation loss of front-end filtering
6. Signal to jammer power ratio (dB), [see ³]
7. Arbitrary or worst case value of the jammer duty factor [>0.001]

³ Values of parameters 6, 8, and 10 have to be chosen so that the error bound used in CATSS is acceptable.

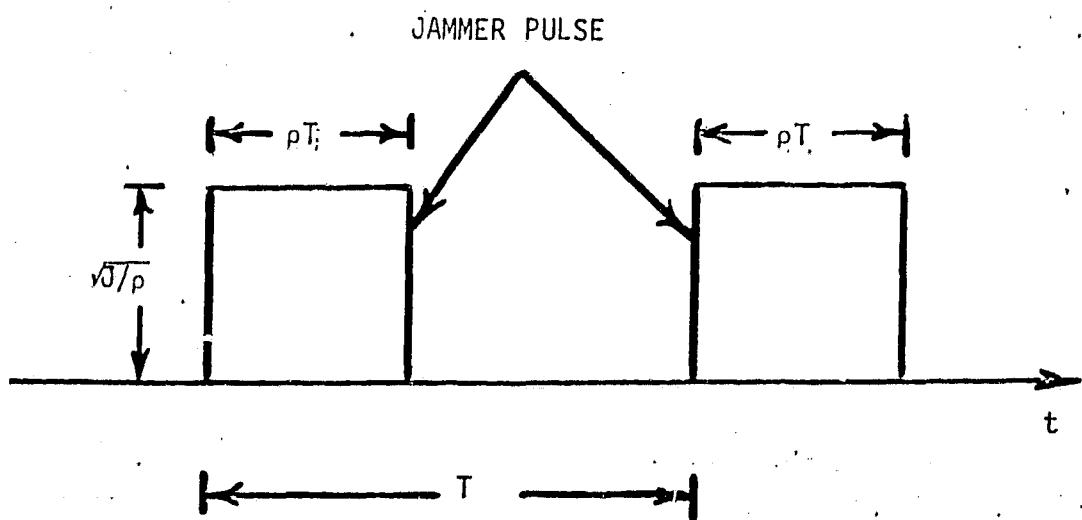
Fig. 4. RF SINGLE ACCESS WITH PN/BPSK MODULATION



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Fig. 5. RF SINGLE ACCESS PN/BPSK JAMMING MODEL

- PULSE JAMMING
- S/J (S = SIGNAL POWER, J = JAMMER
AVERAGE POWER)
- JAMMER DUTY CYCLE ρ



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8. Bit energy to noise spectral density ratio (dB),
[see ³]
9. Chip time - BPF B.W. product [>0.1]
10. Processing gain (dB), [>0]
11. Normalized phase nonlinearity [>0]

3.2.2 CATSS Output

1. BER
2. Performance degradation due to front end filter
3. Performance sensitivity study of system parameters
4. System parameters tradeoff
5. BPSK performance (special case)

3.2.3 Output Format

1. Printed Value
 - (1.1) BER
 - (1.2) Performance degradation due to front end filter
2. Graphic plot
 - (2.1) BER vs related parameter
 - (2.2) Performance degradation vs related parameters

3.3 RF Single Access with FH/MFSK

The RF single access link with FH/FMSK modulation is modeled in Fig. 6. The jammings in this link include full band jamming, partial band jamming, and multiple tone jamming. The models of these jammings are illustrated in Fig. 7.

There are four different kinds of receivers modeled in CATSS, with each one applies to the appropriate jamming model. The general noncoherent MFSK receiver is illustrated in Fig. 8. The signal processing unit for each kind of receiver is shown in Fig. 9.

This link can model the SS/EVA, Free-Flyers forward link with the user interference modeled as jammers.

3.3.1 System Parameters

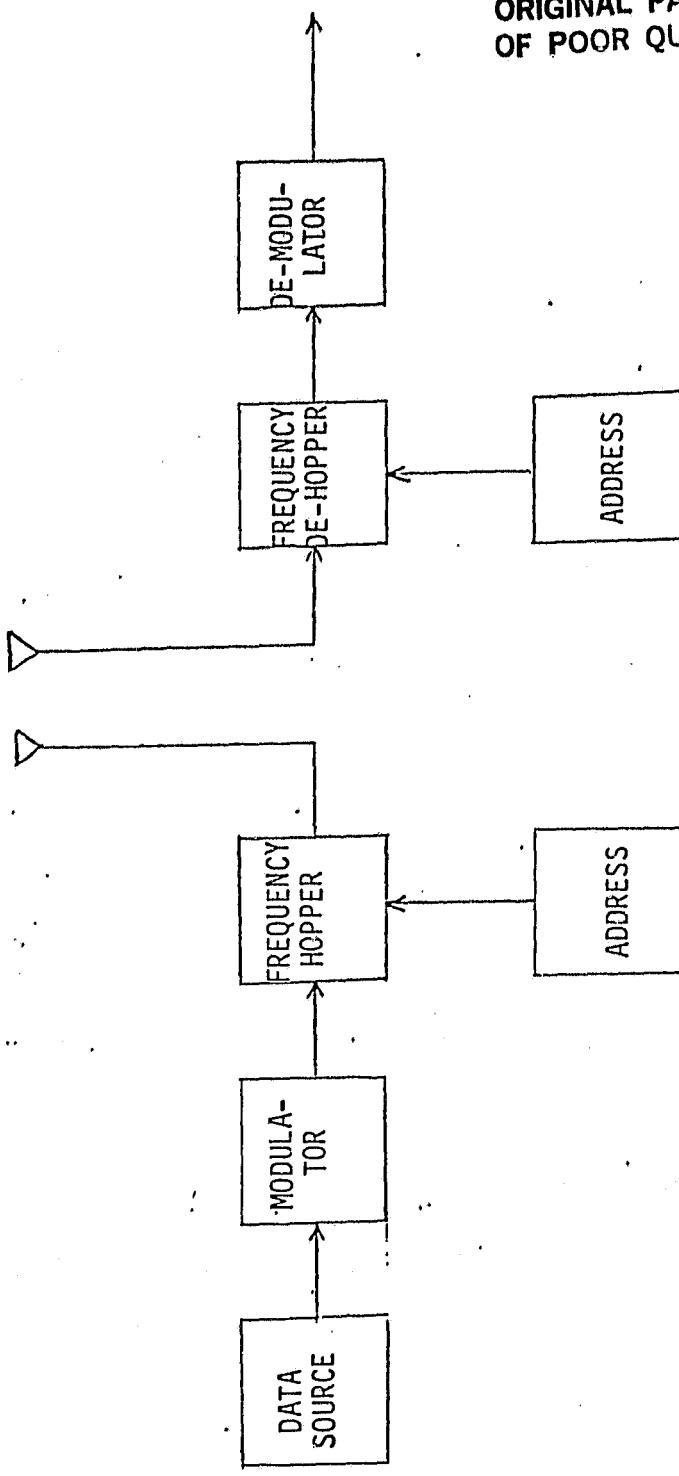
The system parameters are divided into several groups and are illustrated in Table 2. The following lists the parameters along with their limit values.

3.3.1.1 General System Parameters

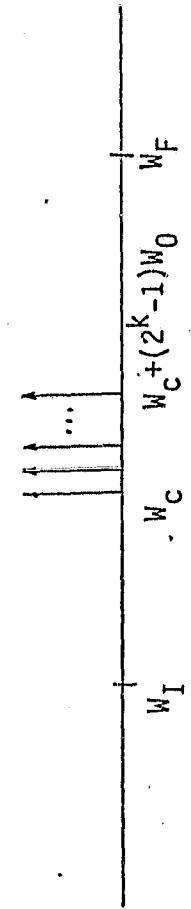
1. Jamming type
2. With or without thermal noise
3. Bit energy to noise spectral density ratio E_b/N_0 , used when thermal noise is included (dB), [see ⁴]
4. Number of orthogonal signals M in MFSK [2,4,8,16,32]
5. Number of hops per symbol, diversity [1<, <8]
6. Coding type
7. Rate of dual-k convolutional code [<1.0]

⁴Values of parameters 3 and 9 have to be chosen so that the error bound used in CATSS is acceptable.

Fig. 6. A FH/MFSK SYSTEM



$2^k \triangleq M$ TONES AVAILABLE FOR SIGNALING



N TONES IN TOTAL WITHIN THE HOPPING BAND

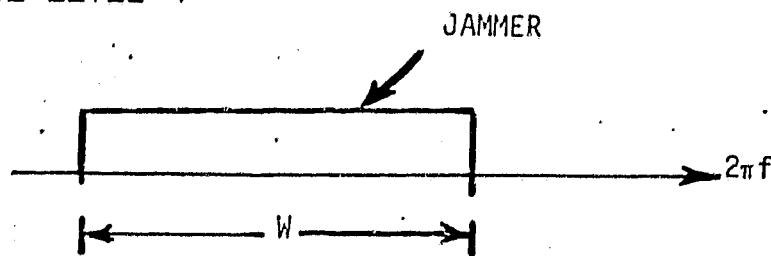
$$w_F = w_I + (N-1)w_0$$

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Fig. 7. RF SINGLE ACCESS FH/MFSK JAMMING MODEL

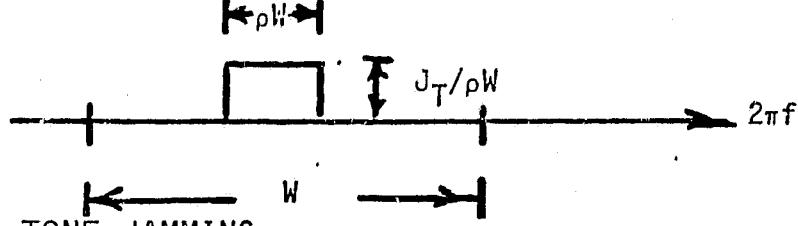
- FULL BAND JAMMING

- JAMMER UNIFORMLY OCCUPIES THE WHOLE HOPPING BANDWIDTH W
- EFFECTIVELY RAISES THE BACKGROUND THERMAL NOISE LEVEL



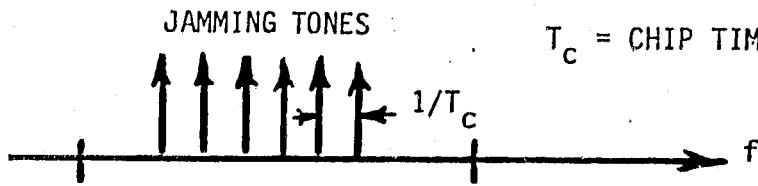
- PARTIAL BAND JAMMING

- JAMMER OCCUPIES A CONTIGUOUS BANDWIDTH ρW ($0 < \rho < 1$) OF THE TOTAL HOPPING BANDWIDTH W



- MULTIPLE TONE JAMMING

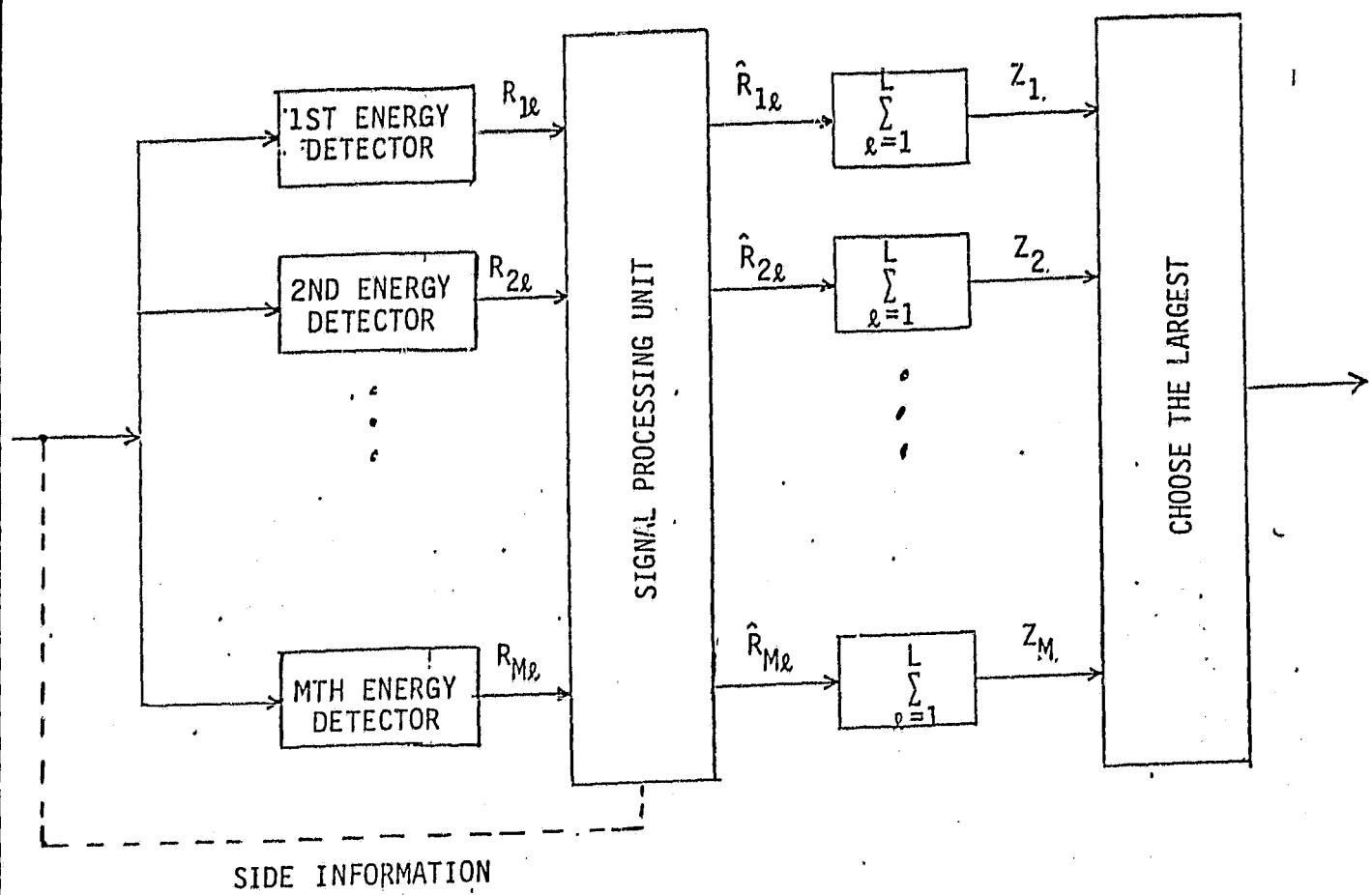
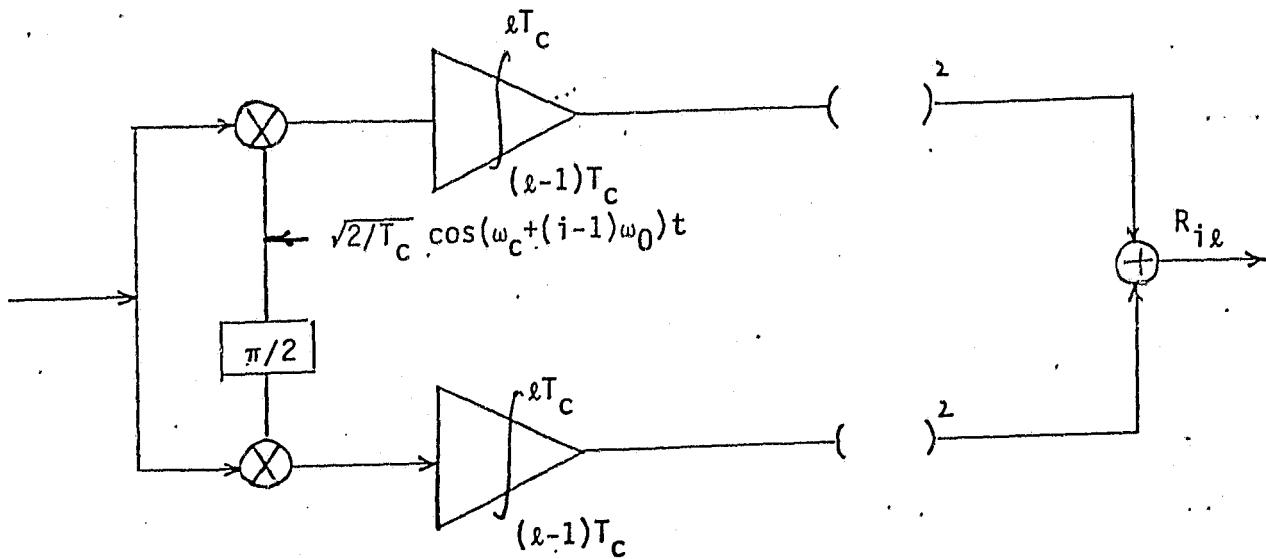
- JAMMERS ARE IN THE FORM OF EQUAL POWER CW SIGNALS WITH FREQUENCIES WITHIN THE HOPPING FREQUENCY RANGE



— HOPPING FREQUENCY RANGE —

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Fig. 8. A GENERAL NONCOHERENT MESK RECEIVER

THE i -th ENERGY DETECTOR

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Fig. 9. FOUR FH/MFSK RECEIVER SIGNAL PROCESSING
UNIT STRUCTURE USED IN CATSS

1. LINEAR COMBINING FOR FULL BAND JAMMING/NO JAMMING

- $\hat{R}_{i\ell} = R_{i\ell}$

2. SUBOPTIMAL WEIGHTING UNDER PARTIAL BAND JAMMING

- ASSUME SIDE INFORMATION ABOUT JAMMER'S STATE IS KNOWN

- $\hat{R}_{i\ell} = \begin{cases} W_u R_{i\ell} & \text{if jammer absent} \\ W_J R_{i\ell} & \text{if jammer present} \end{cases} \quad \text{where } W_u \gg W_J$

3. HARD DECISION COMBINING FOR MULTIPLE TONE JAMMING

- $\hat{R}_{i\ell} = \begin{cases} 1 & \text{if } R_{i\ell} > \gamma > 0 \\ 0 & \text{if } R_{i\ell} \leq \gamma \end{cases}$

4. (LINCOM PROPOSED) RANK-RATIO FOR PARTIAL BAND & MULTIPLE TONE JAMMING

- $R_{i\ell} = f_{i1}(\bar{R}_\ell)W_1 + f_{i2}(\bar{R}_\ell)W_2$

where $\bar{R}_\ell = (R_{1\ell}, R_{2\ell}, \dots, R_{M\ell})$

W_1 & W_2 are weighting (> 0)

and $f_{i1}(\bar{R}_\ell) = \begin{cases} 1 & \text{if } R_{i\ell} = m_{\ell 1} \triangleq \max_k \{R_{k\ell}\}; k=1, \dots, M \\ 0 & \text{otherwise} \end{cases}$

$f_{i2}(\bar{R}_\ell) = \begin{cases} 1 & \text{if } R_{i\ell} = m_{\ell 1} \text{ and } m_{\ell 1}/m_{\ell 2} > \theta > 1 \\ & \text{where } m_{\ell 2} = \text{2nd max}_k \{R_{k\ell}\} \\ 0 & \text{otherwise} \end{cases}$

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Table 2. RF SINGLE ACCESS FH/MFSK SYSTEM PARAMETERS IN CATSS

GENERAL SYSTEM PARAMETERS	PARTIAL BAND JAMMING PARAMETERS	MULTIPLE TONE JAMMING PARAMETERS	RANK-RATIO TEST PARAMETERS
<ul style="list-style-type: none"> JAMMING TYPE FREQ. & TIMING OFFSET THERMAL NOISE E_b/N_0 # OF ORTHOGONAL SIGNALS (M) USED IN MFSK # OF HOPS PER SYMBOL RATE OF DUAL-K CONVOLUTIONAL CODE 	<ul style="list-style-type: none"> RECEIVER STRUCTURE (SUBOPTIMAL WEIGHTING/RANK-RATIO TEST) E_b/N_J $N_J = \text{TOTAL JAMMER POWER}/W$ ARBITRARY/WORST CASE OF E_b/J_b ARBITRARY/WORST CASE OF ρ FOR ALL E_b/N_0 	<ul style="list-style-type: none"> RECEIVER STRUCTURE (HARD LIMITER/RANK RATIO TEST) E_b/N_J ARBITRARY/WORST CASE OF E_b/J_b $J_b \triangleq \text{JAMMER BIT ENERGY}$ S/J 	<ul style="list-style-type: none"> THRESHOLD VALUE θ OF THE RATIO TEST WEIGHT OF RANK TEST w_1 WEIGHT OF RATIO TEST w_2 $S \triangleq \text{SIGNAL POWER}$ $J \triangleq \text{JAMMER POWER PER TONE}$ FOR HIGH E_b/N_0
			ORIGINAL PAGE IS OF POOR QUALITY

8. With or without timing and frequency offset

9. E_b/N_J (dB) [see 4]

where E_b = bit energy

N_J = total jammer power/hopping BW

3.3.1.2 Parameters for full Band Jamming or No Jamming

1. No additional parameter is required

3.3.1.3 Partial Band Jamming Parameters

1. Receiver structure

2. Arbitrary or worst case value of ρ

3. ρ value [$0.01 < \rho < 1.0$], (used when arbitrary value is desired)

*3.3.1.4 Multiple Tone Jamming Parameters

1. Receiver structure

2. Arbitrary or worst case value of S/J

3. S/J value (dB) [>-10 .]

where S = signal power

J = jamme" power per tone

(used when arbitrary S/J is desired)

3.3.1.5 Rank-Ratio Test Parameters

1. Arbitrary or optimal value of threshold

2. Threshold value [>1.0]

(used when arbitrary threshold is desired)

3. Arbitrary or optimal value of weighting w_1 , w_2

4. Weighting w_1 for ranking test [>0]

Options marked with a "" are not fully developed in the software, and will be provided when it is ready.

(used when arbitrary w_1 is desired)

5. Weighting w_2 for ratio test [>0]

(used when arbitrary w_2 is desired)

3.3.2 CATSS Output

3.3.2.1 With No Jamming

1. BER for M-ary orthogonal coding

2. BER for dual-k convolutional coding

3.3.2.2 With Full Band Jamming

1. BER for M-ary orthogonal coding

2. BER for dual-k convolutional coding

3.3.2.3 With Partial Band Jamming

1. BER for M-ary orthogonal coding

2. BER for dual-k convolutional coding

3. In case optimal or worst case values provided by the CATSS are used, the following output are given:

(3.1) Worst case ρ value

(3.2) If suboptimal weighting receiver is used

(3.2.1) Optimal diversity for orthogonal coding with worst case ρ

(3.2.2) Optimal diversity for dual-k convolutional coding with worst case ρ

(3.3) If rank-ratio receiver is used

(3.3.1) Optimal diversity for orthogonal coding with worst case ρ

(3.3.2) Optimal threshold of the rank-ratio test with worst case ρ

(3.3.3) Optimal weight w_1 with worst case ρ

(3.3.4) Optimal weight w_2 with worst case ρ

*3.3.2.4 With Multiple Tone Jamming

1. BER for M-ary orthogonal coding
2. BER for dual-k convolutional coding
3. If rank-ratio receiver is used, the following is also available
 - (3.1) Worst case S/J value for orthogonal code
 - (3.2) Worst case S/J value for dual-k conv. code

*3.3.2.5 Performance Degradation Due to Timing and Frequency Offset.

The analysis here is independent of all the analysis above.

3.3.3 Output Format

1. Printed value
 - (1.1) BER
 - (1.2) Worst case value
 - (1.3) Optimal values
 - (1.4) Performance degradation due to timing and frequency offset
2. Graphic plot
 - (2.1) BER vs appropriate parameter

3.4 RF Multiple Access with FH/MFSK

In this link analysis is performed assuming no jamming exists, and interference due to other users are dominant compared to the thermal noise. The desired signal power is assumed to be the smallest among the users so that a worst case design exists. Under these assumptions, a worst case BER performance is computed. Rank-ratio receiver is used in the analysis.

3.4.1 System Parameters

1. Number of users [>2]
2. Number of tones available in the total hopping bandwidth [$>M$]
3. Number of orthogonal signals used [$M=2,4,8,16,32\dots$]
4. Number of hops per symbol [$>2, <8$]

*3.4.2 CATSS Output

1. BER

3.4.3 Output Format

1. Printed value

(1.1) BER

2. Graphic plot

(2.1) BER versus parameters in Sec. 3.4.1

3.5 Space Optical Communication

The optical communication link is modeled in Fig. 10. In this link no jamming or interference is considered. The system parameters are classified into four different groups and are shown in Table 3.

3.5.1 System Parameters

3.5.1.1 General System Parameters

1. Design BER [$0 < < 1$]

This parameter is used only for no encoding

2. With or without coding

3. Baseband signaling format

This parameter is used only for no encoding

4. Data Rate (MBPS), [> 0]

5. Coding type

6. Code rate (Bit/symbol) [$0 < < 1$]

7. Code word length for block code or constraint

length for convolutional code [> 1]

8. Decoding method, soft or hard decision

9. Symbol size [2,4,8,16,.....]

3.5.1.2 Transmitter Parameters

1. Optical carrier wavelength (nanometer), [> 0]

2. Average transmitting optical power (dBW), [any]

3. Transmitter antenna gain (dB), [> 0]

4. Transmitter optical transmission loss (dB), [< 0]

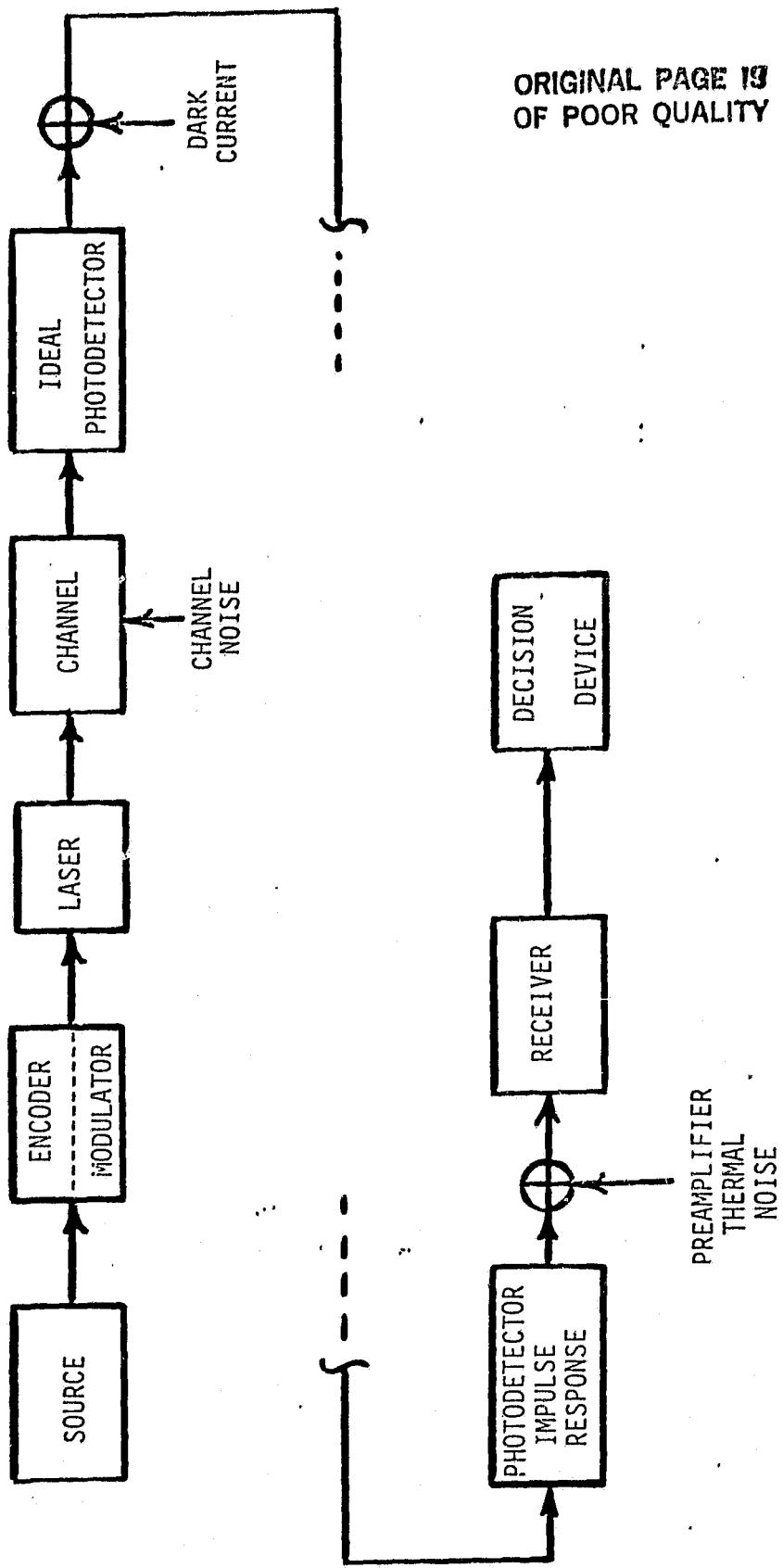
3.5.1.3 Channel Parameters

1. Channel model, Gaussian or Poisson

2. Distance (km), [> 0]

3. Atmospheric absorption loss (dB), [< 0]

Fig. 10. OPTICAL COMMUNICATION LINK MODEL



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Table 3. OPTICAL COMMUNICATION LINK PARAMETERS IN CATSS

GENERAL SYSTEM PARAMETERS	TRANSMITTER PARAMETERS	CHANNEL PARAMETERS	RECEIVER PARAMETERS
• DESIGN BER	• OPTICAL CARRIER WAVELENGTH	• CHANNEL MODEL • GAUSSIAN • POISSON	• EXTINCTION RATIO
• WITH/WITHOUT CODING	• AVERAGE TRANSMITTING OPTICAL POWER	• DISTANCE	• RECEIVER ANTENNA DIAMETER
• BLOCK CODE	• TRANSMITTER ANTENNA GAIN	• ATMOSPHERIC ABSORPTION LOSS	• RECEIVER OPTICAL TRANSMISSION LOSS
• CODE RATE	• TRANSMITTER OPTICAL TRANSMISSION LOSS		• QUANTUM EFFICIENCY
• WORD LENGTH			• MEAN APD GAIN
• CONVOLUTIONAL CODE			• OPTIMAL
• CODE RATE			• ARBITRARY
• CONSTRAINT LENGTH			
• DECODING METHOD			• EFFECTIVE RATIO OF IONIZATION COEFFICIENTS
• SOFT DECISION			• PREAMPLIFIER TEMPERATURE
• HARD DECISION			• EQUIVALENT PRE-AMPLIFIER INPUT IMPEDANCE
• DATA RATE			• AVERAGE SIGNAL COUNT PER SYMBOL TIME
• BASEBAND SIGNALING FORMAT			• AVERAGE NOISE COUNT PER SYMBOL TIME
• NRZ			
• BIPHASE			
• SYMBOL SIZE			

3.5.1.4 Receiver Parameters

1. Extinction ratio [$>0, <1$]
2. Receiver antenna diameter (m), [>0]
3. Receiver optical transmission loss (dB), [<0]
4. Quantum efficiency [$>0, <1$]
5. Arbitrary or optimal APD gain
6. Mean APD gain [>0]

This parameter is used when arbitrary APD gain is chosen.

7. Effective ratio of ionization coefficients [$>0, <1$]
8. Preamplifier temperature (degree k) [>0]
9. Equivalent preamplifier input impedance (ohm) [>0]
10. Arbitrary or computed signal count value
11. Average signal count per symbol time [>0]
12. Average noise count per symbol time [>0]

3.5.2 CATSS Output

3.5.2.1 Uncoded Case

1. Received optical power
2. Optical power required at receiver

3.5.2.2 Coded Case

1. BER

3.5.3 Output Format

1. Printed value

- (1.1) Received optical power
- (1.2) Optical power required at receiver
- (1.3) BER

2. Graphic plot

- (2.1) Received optical power vs related parameter
- (2.2) Optical power required at receiver vs related parameter
- (2.3) BER vs related parameter

4. Instruction for Accessing and Running CATSS

The CATSS system is designed to yield simplicity in accessing and running. It will provide a step by step guidance to the users so that a proper procedure can be followed. All system parameters are defaulted to some values and the users can change any of them for their design purposes. The range of the parameter values are discussed in Section 3 for each link.

4.1 CATSS Running

To access the CATSS, a user simply needs to type the system command

\$ RUN CATSS

and the CATSS will respond with an introductory paragraph of the system.⁵ A choice of one of the five links will allow the user to access that link. In each link an introduction paragraph will show the user the capability and functionality of the link.

A user can get out of a specific link by choosing the "END" parameter and return to the main control routine. In this stage, another link can be accessed similarly.

4.2 CATSS Termination

To terminate CATSS properly, a user only needs to choose the "End of CATSS Analysis" command in the main control routine.

⁵ Refer to the Appendix for the CATSS introductory paragraph.

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APPENDIX
CATSS SAMPLE RUN

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* RUN CATSS

CC AA TT SS SS V1.0

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WELCOME TO CATSS

CATSS (COMMUNICATION ANALYSIS TOOL FOR SPACE STATION)
IS AN INTERACTIVE COMPUTER ANALYSIS AND SIMULATION
TOOL DEVELOPED BY LINCOM CORP. FOR THE SPACE STATION
COMMUNICATION AND TRACKING SYSTEM. IT MODELS AND
ANALYSES THE VARIOUS COMMUNICATION AND TRACKING
LINKS FOR THE SPACE STATION. PLEASE REFER TO THE
USER MANUAL FOR FURTHER DETAIL IN USING THIS ANALYSIS
SYSTEM. THANK YOU.

0 = END OF CATSS ANALYSIS
1 = RF LINK POWER BUDGET
2 = RF SINGLE ACCESS (PN SPREAD) LINK
3 = RF SINGLE ACCESS (FH/MFSK) LINK
4 = RF MULTIPLE ACCESS (FH/MFSK) LINK
5 = SPACE OPTICAL COMMUNICATION LINK
SELECT ONE OF THE ABOVE
1

RF LINK BUDGET ANALYSIS

THE FOLLOWING IS A LIST OF PARAMETERS TO BE DETERMINED

CATSS/LINCOM

1: TRANSMITTER PARABOLIC ANTENNA DIAMETER = 1.000 M
2: TRANSMITTER ANTENNA APERTURE LOSS FACTOR = 0.700
3: RECEIVER PARABOLIC ANTENNA DIAMETER = 1.000 M
4: RECEIVER ANTENNA APERTURE LOSS FACTOR = 0.700
5: DISTANCE BETWEEN TRANSMITTER AND RECEIVER = 2000.000 KM
6: CARRIER FREQUENCY = 30.000 GHZ
7: ATMOSPHERIC ABSORPTION = 0.0100 DB/KM

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

0

ENTER 1=END. 2=RESULT PRINT OUT. 3=SENSITIVITY CURVE
2

TRANSMITTER ANTENNA GAIN = 48.394 DB
RECEIVER ANTENNA GAIN = 48.394 DB
FREE SPACE LOSS = -188.005 DB
ATMOSPHERIC ABSORPTION LOSS = -20.000 DB
TOTAL GAIN/LOSS = -111.217 DB

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ENTER 1=END, 2=RESULT PRINT OUT, 3=SENSITIVITY CURVE

3

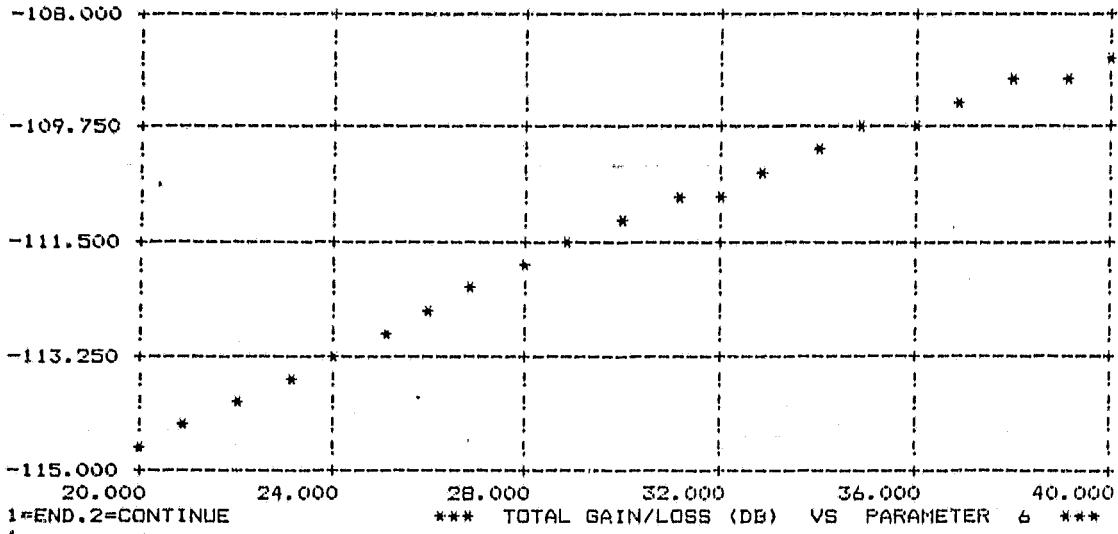
ENTER THE PARAMETER NUMBER TO BE VARIED

6

ENTER THE LOWER, UPPER LIMIT, AND NUMBER OF POINTS IN PLOTTING

20. 40. 21

PARAMETER 6 VALUE	TOTAL GAIN/LOSS (DB)
20.000	-114.739
21.000	-114.315
22.000	-113.911
23.000	-113.525
24.000	-113.155
25.000	-112.800
26.000	-112.460
27.000	-112.132
28.000	-111.816
29.000	-111.511
30.000	-111.217
31.000	-110.932
32.000	-110.656
33.000	-110.389
34.000	-110.130
35.000	-109.878
36.000	-109.633
37.000	-109.395
38.000	-109.164
39.000	-108.938
40.000	-108.718



1=END, 2=CONTINUE

1

END OF RF POWER BUDGET

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- 0 = END OF CATSS ANALYSIS
- 1 = RF LIM, POWER BUDGET
- 2 = RF SINGLE ACCESS (PN SPREAD) LINK
- 3 = RF SINGLE ACCESS (FH/MFSK) LINK
- 4 = RF MULTIPLE ACCESS (FH/MFSK) LINK
- 5 = SPACE OPTICAL COMMUNICATION LINK

SELECT ONE OF THE ABOVE
2

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RF SINGLE ACCESS LINK WITH PN SPREAD MODULATION.
IT APPLIES TO THE FOLLOWING CASES:

CATSS/LINCOM

- 1. SPACE STATION / RELAY SATELLITE
- 2. SPACE STATION / SPACE SHUTTLE ORBITER
- 3. SPACE STATION / ORBITAL TRANSFER VEHICLES
- 4. SPACE STATION / EVA, FREE-FLYERS WIDEBAND

THE ANALYSIS IN THIS SECTION PROVIDES

- 1. BER VS EB/NO
- 2. BER PERFORMANCE IN THE PRESENCE OF PULSE JAMMING
(BER VS S/J AND JAMMER DUTY CYCLE)
- 3. PERFORMANCE DEGRADATION DUE TO FRONT END FILTER CORRELATION LOSS
- 4. PERFORMANCE WITH OR WITHOUT CONVOLUTIONAL CODE
(HARD/SOFT DECISION, INTERLEAVING)
- 5. PERFORMANCE SENSITIVITY OF SYSTEM PARAMETERS
- 6. BER PERFORMANCE OF STANDARD BPSK (WITH 0 DB PROCESSING GAIN)

THE FOLLOWING IS A LIST OF PARAMETERS TO BE DETERMINED

CATSS/LINCOM

- 1: CHOICE FOR CORRELATION LOSS(CL) = 3
(1 = PERFORMANCE WITHOUT TAKING CL INTO CONSIDERATION)
(2 = ONLY THE CL IS DESIRED)
(3 = PERFORMANCE TAKING CL INTO CONSIDERATION)
- 2: CHOICE OF DECODING DECISION / INTERLEAVING = 2
(1 = HARD DECISION WITH INTERLEAVING)
(2 = SOFT DECISION WITH INTERLEAVING)
(3 = NO INTERLEAVING, WORST CASE)
- 3: CHOICE OF CONVOLUTIONAL CODE (CONSTRAINT LENGTH,CODE RATE) = 2
(1 = BEST (5,1/2) C.C.)
(2 = BEST (7,1/2) C.C.)
(3 = BEST (7,1/3) C.C.)
(4 = UNCODED)
- 4: CHOICE OF JAMMER DUTY FACTOR = 1
1 = WORST CASE
2 = USE VALUE IN PARAMETER 12
- 11: SIGNAL TO JAMMER POWER RATIO = -20.0000 DB
- 12: DUTY FACTOR OF THE JAMMER (>0.001) = 0.5000
- 13: BIT ENERGY TO NOISE SPECTRAL DENSITY RATIO = 10.0000 DB
- 14: PRE-DESPREADING BPF BW*CHIP TIME = 2.00
- 15: PROCESSING GAIN = 30.00 DB
- 16: NORMALIZED PHASE NONLINEARITY(>=0.) = 0.01

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

0

ENTER 1=END. 2=RESULT PRINT OUT. 3=SENSITIVITY CURVE
2

CORRELATION LOSS = -0.8933 DB
BER = 0.35102E-12
WORST CASE VALUE OF JAMMER DUTY FACTOR = 0.150

ENTER 1=END. 2=RESULT PRINT OUT. 3=SENSITIVITY CURVE
3

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- 1 - CORRELATION LOSS VS PARAMETER
- 2 - BER VS PARAMETER
- 3 - WORST CASE RHO VS PARAMETER

2

ENTER THE PARAMETER NUMBER (>10 ONLY) TO BE VARIED.

15

ENTER THE LOWER, UPPER LIMIT, AND NUMBER OF POINTS IN PLOTTING

20. 30. 21

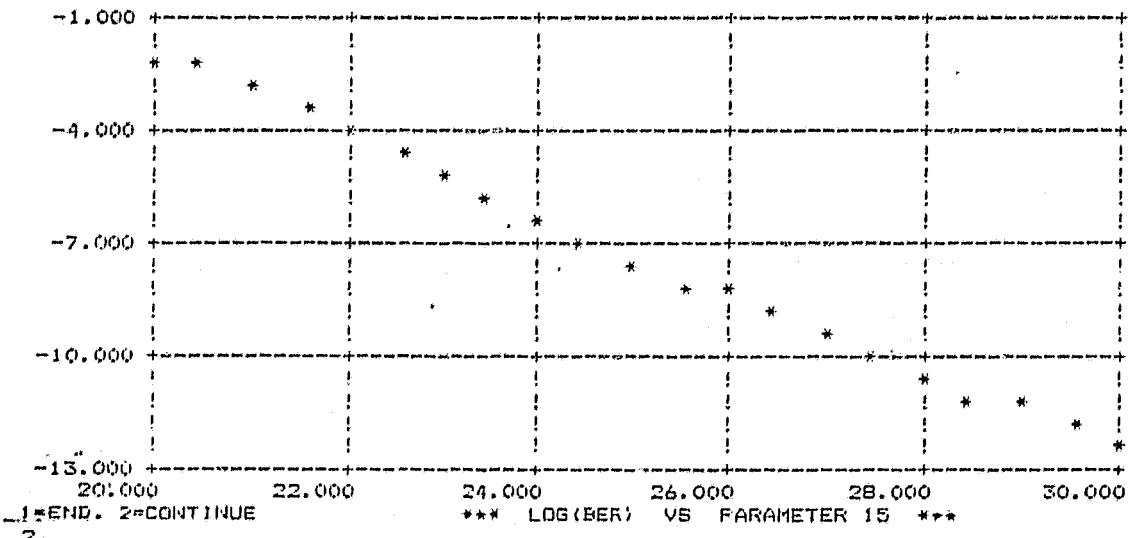
PARAMETER = PARAMETER 15 VALUE

OUTPUT 1 = CORRELATION LOSS (DB)

OUTPUT 2 = WORST CASE VALUE OF JAMMER DUTY FACTOR (RHO)

OUTPUT 3 = BIT ERROR RATE

PARAMETER	OUTPUT 1	OUTPUT 2	OUTPUT 3
20.00 DB	-0.893	1.000	0.11318E-01
20.50 DB	-0.893	1.000	0.32313E-02
21.00 DB	-0.893	1.000	0.86964E-03
21.50 DB	-0.893	0.950	0.22283E-03
22.00 DB	-0.893	0.850	0.58937E-04
22.50 DB	-0.893	0.750	0.16290E-04
23.00 DB	-0.893	0.700	0.46632E-05
23.50 DB	-0.893	0.600	0.13737E-05
24.00 DB	-0.893	0.550	0.41150E-06
24.50 DB	-0.893	0.500	0.12457E-06
25.00 DB	-0.893	0.450	0.38129E-07
25.50 DB	-0.893	0.400	0.11806E-07
26.00 DB	-0.893	0.350	0.36896E-08
26.50 DB	-0.893	0.300	0.11547E-08
27.00 DB	-0.893	0.250	0.35389E-09
27.50 DB	-0.893	0.250	0.11368E-09
28.00 DB	-0.893	0.200	0.35274E-10
28.50 DB	-0.893	0.200	0.11318E-10
29.00 DB	-0.893	0.150	0.33868E-11
29.50 DB	-0.893	0.150	0.11418E-11
30.00 DB	-0.893	0.150	0.35102E-12



1-END. 2=CONTINUE

2

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THE FOLLOWING IS A LIST OF PARAMETERS TO BE DETERMINED

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- 1: CHOICE FOR CORRELATION LOSS(CL) = 3
(1 = PERFORMANCE WITHOUT TAKING CL INTO CONSIDERATION)
(2 = ONLY THE CL IS DESIRED)
(3 = PERFORMANCE TAKING CL INTO CONSIDERATION)
- 2: CHOICE OF DECODING DECISION / INTERLEAVING = 2
(1 = HARD DECISION WITH INTERLEAVING)
(2 = SOFT DECISION WITH INTERLEAVING)
(3 = NO INTERLEAVING, WORST CASE)
- 3: CHOICE OF CONVOLUTIONAL CODE (CONSTRAINT LENGTH,CODE RATE) = 2
(1 = BEST (5,1/2) C.C.)
(2 = BEST (7,1/2) C.C.)
(3 = BEST (7,1/3) C.C.)
(4 = UNCODED)
- 4: CHOICE OF JAMMER DUTY FACTOR = 1
1 = WORST CASE
2 = USE VALUE IN PARAMETER 12
- 11: SIGNAL TO JAMMER POWER RATIO = -20.0000 DB
- 12: DUTY FACTOR OF THE JAMMER (>0.001) = 0.0010
- 13: BIT ENERGY TO NOISE SPECTRAL DENSITY RATIO = 10.0000 DB
- 14: PRE-DESPREADING BPF BW*CHIP TIME = 2.00
- 15: PROCESSING GAIN = 30.00 DB
- 16: NORMALIZED PHASE NONLINEARITY(>=0.) = 0.01

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

4

ENTER NEW VALUE FOR PARAMETER 4
2

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

12

ENTER NEW VALUE FOR PARAMETER 12
0.5

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

0

THE CURRENT VALUES FOR THE RF SINGLE ACCESS PN SPREAD LINK ARE

- 1: CHOICE FOR CORRELATION LOSS(CL) = 3
(1 = PERFORMANCE WITHOUT TAKING CL INTO CONSIDERATION)
(2 = ONLY THE CL IS DESIRED)
(3 = PERFORMANCE TAKING CL INTO CONSIDERATION)
- 2: CHOICE OF DECODING DECISION / INTERLEAVING = 2
(1 = HARD DECISION WITH INTERLEAVING)
(2 = SOFT DECISION WITH INTERLEAVING)
(3 = NO INTERLEAVING, WORST CASE)
- 3: CHOICE OF CONVOLUTIONAL CODE (CONSTRAINT-LENGTH,CODE RATE) = 2
(1 = BEST (5,1/2) C.C.)
(2 = BEST (7,1/2) C.C.)
(3 = BEST (7,1/3) C.C.)
(4 = UNCODED)
- 4: CHOICE OF JAMMER DUTY FACTOR = 2
1 = WORST CASE
2 = USE VALUE IN PARAMETER 12
- 11: SIGNAL TO JAMMER POWER RATIO = -20.0000 DB
- 12: DUTY FACTOR OF THE JAMMER (>0.001) = 0.5000
- 13: BIT ENERGY TO NOISE SPECTRAL DENSITY RATIO = 10.0000 DB
- 14: PRE-DESPREADING BPF BW*CHIP TIME = 2.00
- 15: PROCESSING GAIN = 30.00 DB
- 16: NORMALIZED PHASE NONLINEARITY(>=0.) = 0.01

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ENTER 1=END, 2=RESULT PRINT OUT, 3=SENSITIVITY CURVE
3

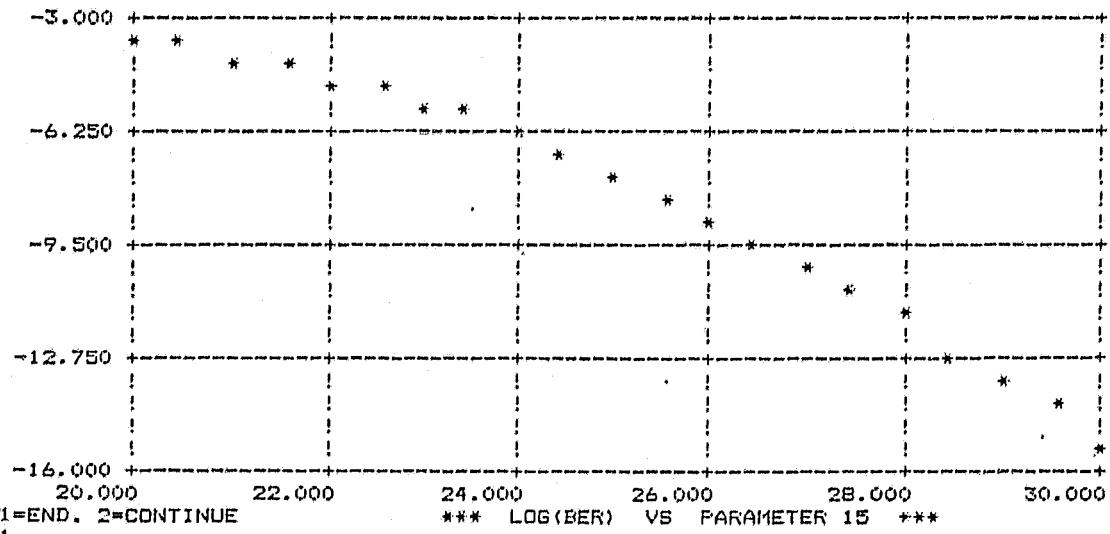
1 = CORRELATION LOSS VS PARAMETER
2 = BER VS PARAMETER
3 = WORST CASE RHO VS PARAMETER

2
ENTER THE PARAMETER NUMBER (>10 ONLY) TO BE VARIED,
15

ENTER THE LOWER, UPPER LIMIT, AND NUMBER OF POINTS IN PLOTTING
20. 30. 21

PARAMETER = PARAMETER 15 VALUE
OUTPUT 1 = CORRELATION LOSS (DB)
OUTPUT 2 = BIT ERROR RATE

PARAMETER	OUTPUT 1	OUTPUT 2
20.00 DB	-0.893	0.35639E-03
20.50 DB	-0.893	0.18846E-03
21.00 DB	-0.893	0.94508E-04
21.50 DB	-0.893	0.44804E-04
22.00 DB	-0.893	0.20010E-04
22.50 DB	-0.893	0.83860E-05
23.00 DB	-0.893	0.32831E-05
23.50 DB	-0.893	0.11948E-05
24.00 DB	-0.893	0.40218E-06
24.50 DB	-0.893	0.12457E-06
25.00 DB	-0.893	0.35331E-07
25.50 DB	-0.893	0.91381E-08
26.00 DB	-0.893	0.21478E-08
26.50 DB	-0.893	0.45769E-09
27.00 DB	-0.893	0.88329E-10
27.50 DB	-0.893	0.15446E-10
28.00 DB	-0.893	0.24526E-11
28.50 DB	-0.893	0.35505E-12
29.00 DB	-0.893	0.47142E-13
29.50 DB	-0.893	0.57870E-14
30.00 DB	-0.893	0.66339E-15



END OF RF SINGLE ACCESS WITH PN SPREAD

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0 = END OF CATSS ANALYSIS
1 = RF LINK POWER BUDGET
2 = RF SINGLE ACCESS (PN SPREAD) LINK
3 = RF SINGLE ACCESS (FH/MFSK) LINK
4 = RF MULTIPLE ACCESS (FH/MFSK) LINK
5 = SPACE OPTICAL COMMUNICATION LINK
SELECT ONE OF THE ABOVE
3

RF SINGLE ACCESS LINK WITH FH/MFSK MODULATION

THE ANALYSIS IN THIS SECTION PROVIDES

1. BER PERFORMANCE WITH NO JAMMING
 - * WITH ORTHOGONAL CODE
 - * WITH DUAL-K C.C.
2. BER PERFORMANCE WITH FULL BAND JAMMING
 - * WITH ORTHOGONAL CODE
 - * WITH DUAL-K C.C.
3. PERFORMANCE WITH PARTIAL BAND JAMMING
 - * BER WITH M-ARY ORTHOGONAL CODING
 - * BER WITH DUAL-K CONVOLUTIONAL CODING
 - * IF OPTIMAL OR WORST CASE VALUES ARE USED
 - * WORST CASE RHO VALUE
 - * SUBOPTIMAL WEIGHTING RECEIVER
 - * OPTIMAL DIVERSITY FOR ORTHOGONAL CODING WITH WORST CASE RHO
 - * OPTIMAL DIVERSITY FOR DUAL-K CONVOLUTIONAL CODING WITH WORST CASE RHO
 - * RANK-RATIO TEST RECEIVER
 - * OPTIMAL DIVERSITY FOR ORTHOGONAL CODING WITH WORST CASE RHO
 - * OPTIMAL THRESHOLD OF THE RANK-RATIO TEST WITH WORST CASE RHO
 - * OPTIMAL WEIGHT W1 WITH WORST CASE RHO
 - * OPTIMAL WEIGHT W2 WITH WORST CASE RHO
4. PERFORMANCE WITH MULTIPLE TONE JAMMING
 - * BER WITH ORTHOGONAL CODE
 - * BER WITH DUAL-K CONVOLUTIONAL CODE
 - * IF RANK-RATIO TEST RECEIVER IS USED, THE FOLLOWING IS ALSO PROVIDED
 - * WORST CASE VALUE OF S/J WITH ORTHOGONAL CODE
 - * WORST CASE VALUE OF S/J WITH DUAL-K CONV. CODE
5. BER PERFORMANCE WITH IMPERFECT TIME AND FREQUENCY SYNCHRONIZATION

THE FOLLOWING IS A LIST OF PARAMETERS TO BE DETERMINED

CATSS/LINCOM

A: GENERAL SYSTEM PARAMETERS:

- 1: JAMMING TYPE = 1
 - 1 = PARTIAL BAND JAMMING
 - 2 = MULTIPLE TONE JAMMING
 - 3 = NO JAMMING/FULL BAND JAMMING
- 2: THERMAL NOISE CONSIDERATION = 2
 - 1 = WITHOUT THERMAL NOISE
 - 2 = WITH THERMAL NOISE
- 3: BIT ENERGY TO NOISE SPECTRAL DENSITY RATIO = 10.000 DB
(USED WHEN PARAMETER 2 = 2)
- 4: NUMBER OF ORTHOGONAL SIGNALS M (MFSK) = 16
- 5: NUMBER OF HOPS PER SYMBOL = 4
 - IF (PARM 1 = 1 AND PARM 32 = 2) OR
(PARM 1 = 2 AND PARM 42 = 2)

THEN AN OPTIMAL DIVERSITY VALUE COMPUTED BY CATSS WILL BE USED

- 6: CODING TYPE = 1
 - 1 = ORTHOGONAL CODING
 - 2 = DUAL-K CONVOLUTIONAL CODING
- 7: RATE OF DUAL-K CONVOLUTIONAL CODE = 0.5000
- 8: TIMING AND FREQUENCY OFFSET = 1
 - 1 = WITHOUT INCLUDING
 - 2 = INCLUDING
(IT TAKES VERY LONG CPU TIME TO INCLUDE TIMING AND
FREQUENCY OFFSET. BATCH JOB PROCESSING IS ADVISABLE.)
- 9: EB/NJ = 10.000 DB
WHERE EB = BIT ENERGY
NJ = TOTAL JAMMER POWER / HOPPING BW (RAD)

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B: NO JAMMING/FULL BAND JAMMING PARAMETERS:
NO ADDITIONAL PARAMETER IS REQUIRED

C: PARTIAL BAND JAMMING PARAMETERS:

- 31: RECEIVER STRUCTURE = 1
 - 1 = SUBOPTIMAL WEIGHTING
 - 2 = RANK-RATIO TEST
- 32: RHO VALUE CONSIDERATION = 1
 - 1 = USE THE VALUE IN PARAMETER 33
 - 2 = USE THE WORST CASE VALUE COMPUTED BY CATSS
- 33: VALUE OF RHO = 0.300
WHERE RHO IS THE PORTION OF HOPPING BW JAMMED, ASSUMED CONTIGUOUS

D: MULTIPLE TONE JAMMING PARAMETERS:

- 41: RECEIVER STRUCTURE = 1
 - 1 = HARD LIMITER
 - 2 = RANK-RATIO TEST
- 42: S/J CONDITION = 2
 - 1 = USE S/J VALUE IN PARAMETER 43
 - 2 = USE WORST CASE S/J VALUE AS COMPUTED BY CATSS
(PARAMETER 42 IS USED ONLY WHEN PARAMETER 41 = 2)
- 43: SIGNAL POWER / JAMMER POWER PER TONE = 0.00 DB

E: RANK-RATIO TEST PARAMETERS:

- 51: THRESHOLD OF RATIO TEST = 2
 - 1 = USE THE VALUE IN PARAMETER 52
 - 2 = USE THE OPTIMAL VALUE COMPUTED BY CATSS
- 52: THRESHOLD VALUE = 3.00
- 53: WEIGHTING = 2
 - 1 = USE THE VALUES IN PARAMETERS 54 & 55
 - 2 = USE THE OPTIMAL WEIGHTINGS COMPUTED BY CATSS
- 54: WEIGHTING FOR RANKING TEST, W1 = 1.00
- 55: WEIGHTING FOR RATIO TEST, W2 = 1.00

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE

0

ENTER 1=END, 2=RESULT PRINT OUT, 3=SENSITIVITY CURVE

2

WITH PARTIAL BAND JAMMING:

BER FOR M-ARY ORTHOGONAL CODING = 0.90418E-02
BER FOR DUAL-K CONVOLUTIONAL CODING = 0.10540E-09

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ORIGINAL PAGE IS
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0 = END OF CATSS ANALYSIS
1 = RF LINK POWER BUDGET
2 = RF SINGLE ACCESS (PN SPREAD) LINK
3 = RF SINGLE ACCESS (FH/MFSK) LINK
4 = RF MULTIPLE ACCESS (FH/MFSK) LINK
5 = SPACE OPTICAL COMMUNICATION LINK
SELECT ONE OF THE ABOVE
5

THIS PART OF LINK ANALYSIS INCLUDES TWO PARTS.
THE LINK BUDGET ANALYSIS AND PERFORMANCE EVALUATION.

CATSS/LINCOM

1. THE LINK BUDGET ANALYSIS DETERMINES THE OPTICAL POWER AVAILABLE AT THE OPTICAL RECEIVER GIVEN THE PARAMETERS IN THE OPTICAL TRANSMITTER AND THE CHANNEL.
2. PERFORMANCE EVALUATION
 - 2.1 UNCODED CASE
THE RECEIVER DESIGN DETERMINES THE REQUIRED OPTICAL POWER AT THE RECEIVER GIVEN A SET OF RECEIVER PARAMETERS TO ACHIEVE THE DESIRED PERFORMANCE (BIT ERROR RATE). TO MEET THE LINK REQUIREMENT, THE OPTICAL POWER SHOULD BE GREATER THAN (WITH A MARGIN) THE REQUIRED OPTICAL POWER.
 - 2.2 CODED CASE
THE BER VALUES (RANDOM CODING BOUND AND UNION BOUND) ARE EVALUATED.

THE FOLLOWING IS A LIST OF PARAMETERS TO BE DETERMINED

CATSS/LINCOM

1: DESIGN BIT ERROR RATE(USED IN UNCODED CASE) = 0.10000E-08
2: CODING IN USE (1=NO, 2=YES) = 1
3: BASEBAND SIGNALING FORMAT(No CODING) = 2 (1=NRZ, 2=BIPHASE)
4: EXTINCTION RATIO = 0.0500
5: DATA RATE = 100.000 MBPS
6: OPTICAL CARRIER WAVELENGTH = 0.550000 NM
7: CHANNEL MODEL = 1 (1=GAUSSIAN, 2=POISSON)
8: DECODING METHOD = 2 (1=SOFT, 2=HARD)
9: SYMBOL SIZE = 2.0
10: CODING TYPE = 2 (1=BLOCK CODE, 2=CONVOLUTIONAL CODE)
11: CODE RATE = 0.3333 BITS/SYMBOL
12: WORD LENGTH (B.C.) OR CONSTRAINT LENGTH (C.C.) = 5.0
13: MINIMUM DISTANCE FOR THE CODE USED = 7.0
31: AVERAGE TRANSMITTING OPTICAL POWER = -10.00 DBW
32: TRANSMITTER ANTENNA GAIN = 80.00 DB
33: TRANSMITTER OPTICAL TRANSMISSION LOSS = -5.00 DB
61: DISTANCE = 200.0 KM
62: ATMOSPHERIC ABSORPTION LOSS = 0.00 DB
91: RECEIVER ANTENNA DIAMETER = 0.250 M
92: RECEIVER OPTICAL TRANSMISSION LOSS = -8.50 DB
93: QUANTUM EFFICIENCY = 0.850
94: CHOICE OF MEAN APD GAIN = 1 (1=OPTIMAL GAIN, 2=ARBITRARY GAIN)
95: MEAN APD GAIN = 200.00
96: EFFECTIVE RATIO OF IONIZATION COEFFICIENTS = 0.03
97: PREAMPLIFIER TEMPERATURE = 300.0 DEG K
98: EQUIVALENT FREAMPLIFIER INPUT IMPEDANCE = 100.0 OHMS
99: SIGNAL COUNT = 1
 (1=USE CALCULATED SIGNAL COUNT VALUE
 2=USE INPUT SIGNAL COUNT VALUE)
100: AVERAGE SIGNAL COUNT PER SYMBOL TIME = 30.000
101: AVERAGE NOISE COUNT PER SYMBOL TIME = 5.000

ENTER THE PARAMETER NUMBER FOR THE ONE TO BE REDEFINED
ENTER 0 FOR NO PARAMETER CHANGE
0

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ENTER 1 = END
2 = RESULT PRINT OUT
3 = SENSITIVITY CURVE

2

THE RECEIVED OPTICAL POWER = -73.603 DBW
THE OPTICAL POWER REQUIRED AT RECEIVER = -74.171 DBW

1 = END OF OPTICAL LINK ANALYSIS
2 = CONTINUE OPTICAL LINK ANALYSIS
1

END OF OPTICAL LINK ANALYSIS

0 = END OF CATSS ANALYSIS
1 = RF LINK POWER BUDGET
2 = RF SINGLE ACCESS (PN SPREAD) LINK
3 = RF SINGLE ACCESS (FH/MFSK) LINK
4 = RF MULTIPLE ACCESS (FH/MFSK) LINK
5 = SPACE OPTICAL COMMUNICATION LINK
SELECT ONE OF THE ABOVE
0

THANK YOU FOR USING CATSS

HAVE A NICE DAY

LINCOM CORP

FORTRAN STOP

LinCom